7. Data Entry Devices and Procedures

7.1 Definition of Data Entry

Data entry refers to man to machine communication. This communication is typically accomplished by using keyboards, switches, levers, or dials, mark-sense answer sheets, graphic input, constrained handwriting, or the voice. Only data which are symbolic, and in digital rather than in analog form, are considered here.

The task of entering data may consist of simple operations, such as keying from clear unambiguous hard copy, or of more complex ones, such as copying while resolving ambiguity in the original copy, or of very complex ones which may entail man-machine interaction involving problem solving or information retrieval. The emphasis here will be on tasks at the simpler end of the continuum, not because they are more important but because there are little or no data to provide design guidelines for data entry tasks at the "interacting" end.

7.2 Characteristics of the Input Source to the Operator

7.2.1 Clarity and Orderliness

The clarity and orderliness with which data are presented to a data entry operator critically affect his speed and accuracy. In the typical high-volume data entry task, an operator receives information from a source document (a printed page, written report, or notations in handwritten script) and transduces the data into some machine readable form. If the operator has to skip around or decipher partially illegible letters, numbers, or character combinations, he will tend to make errors and enter the data slowly. The occasional entry task usually gives the operator time to locate and decipher the data to be entered, but if the entry must be made under pressure, orderliness and clarity are again needed for speed and accuracy. This principle is an inference from search time and discriminability studies, and the studies cited below. There are no directly supporting data.

7.2.2 Ordering of Source and Object Documents

A different ordering of entries on the source document relative to the punched card or object document degrades performance. Klemmer and Lockhead (1960), for example, report that there is general agreement that a job which may require skipping around the source document will yield lower performance figures than one in which the source document information is in the same format as the card to be punched.

7.2.3 Source Document Legibility

Klemmer and Lockhead (1960) report general agreement among supervisors that legibility is important for speed and accuracy in key punching. Handwritten documents do not necessarily indicate poor legibility, and they find no consistent difference between printed and handwritten source documents in terms of operator performance.

7.2.4 Format of Source Document

Seemingly small changes in job format may be a hindrance to production. New operators can learn a new format about as easily as new operators formerly learned an old format. However, operators who are experienced on the old format may not regain their former speed after working on a new format for as long as six months (Klemmer and Lockhead, 1960).

7.2.5 Readability of Source Document

Poulton and Brown (1968) studied reading rates of all upper case printing (the form for

most data processing systems), versus a mixture of upper and lower case printing. The printing in conventional upper and lower case characters was read 13% faster and comprehended better. While speed of reading and amount of comprehension are not directly related to data entry, both can be expected to affect speed of entry.

7.2.6 Grouping of Data Characters and Length of Message

Conrad and Hull (1967) report on the copying of "random" strings of characters by hand. Strings were either 3, 6, 9, or 12 characters long. Increased length led to more errors. Each string of digits was either grouped in sets of three characters or printed in one long string, and for the 12-digit strings, grouping led to greater accuracy. Additional supporting data are supplied by Smith (1967). Subjects entered 3-, 6-, or 10-digit messages, and errors increased with length of message. Conrad and Hille (1957, cited in Conrad, 1960b) suggest groups of three or four digits are optimum in size.

7.2.7 Isolation of Data to be Entered

Deininger (1960b) reports that the manner in which unfamiliar numbers are displayed is important. Keying unfamiliar numbers from the pages of a telephone directory can increase keying times by 75% and keying errors by 100% in in comparison with keying from a 3- x 5-in. file card on which only one number is typed.

7.2.8 Redundancy of Input

The higher the redundancy of the data being entered, at least up to the limits of normal English text, the faster the data entry and the fewer the errors. Normal English text contains a great deal of higher order sequential constraint. That is, redundancy is much higher than that indicated by the simple frequencies of occurrence of the letters of the alphabet e. g., Miller et al. (1958) and Seibel (1963b).

The effects of redundancy on a data entry task are most directly demonstrated in the study by Hershman and Hillix (1965). Normal text was typed somewhat faster than random words, and random words were typed much faster than random characters. Conrad (1960a) reports similar results for varying orders of approximation to the names of English towns.

Number of Characters Exposed

In the Hershman and Hillix (1965) study the typist was able to see 1, 2, 3, 6, or an unlimited number of characters at a time. The more characters that were exposed, the more accurate the typing for text and random word material. For random characters, however, there was little improvement beyond that obtained by exposing three characters at a time.

Age with respect to redundancy and data entry rate. Rabbitt and Birren (1967) report that people over the age of sixty appear not to take advantage of high degrees of redundancy to the same extent as people between the ages of 17 and 28 years. Differences in "taking advantage of redundancy" may be important in determining data entry proficiency, regardless of age.

Number of Different Characters

It is important to note that the principle concerning redundancy of material refers to the rate of *character* entry, not the rate of information (bits) entry. If a particular data entry job involves random (or near random) strings of alpha (26) or alphanumeric (36) characters, that job has more information per character than a job with correspondingly random numeric (10) characters only. The job with more information will tend to be entered more slowly (in terms of character entry rate), and with more error.

Alphanumeric vs. Numeric Data

Alphabetic messages are usually in a form approaching normal words or text, and as a result are highly redundant. This tends not to be true of numeric data, i. e., they have very little redundancy. Klemmer and Lockhead (1960) report no consistent difference between alphanumeric and straight numeric keypunching.

Subsets of Alphabetic Characters

Messages composed of random arrangements of just ten of the possible alphabetic characters will not be entered as well as straight numeric messages. The operator has learned to expect

the occurrence of all 26 characters whenever the alphabet is used. Further, this kind of experience continues during off-work hours. The operator cannot easily take advantage of a restriction to an artificial subset of 10 of the 26 alphabetic characters. (See Conrad and Hull, 1967, and Fitts and Switzer, 1962.)

Information per Keystroke

Data entry messages should, wherever feasible, be designed to be short, by making each character entered convey a large amount of information. See Deininger et al. (1966). Such design will lead to more *messages* (not characters, however) entered per minute. The design may be accomplished by manipulating alphabet size, i.e., number of different characters used, or by manipulating the effective number of keys on the data entry keyboard (e.g., Minor and Pitman, 1965).

Source Document Redundancy and Short-Term Memory

Many data entry tasks impose a short-term memory load on the operator, or the operator may choose to perform his task utilizing his short-term memory for "chunks" (Miller, 1956) or "fields" of the message. This is most likely in situations calling for occasional data entries, in situations where the operator must search for "chunks" of a message in various parts of a source document, or in table look-up tasks such as the finding and entering of a telephone number. When an operator holds a message, or part of a message, in memory, the activity of keying the initial portion of that message is disruptive to the retention of the rest of the message. This is true even if the initial portion of the message is completely redundant (i.e., it is always the same character, or set of characters, for all messages to be keyed).

Thus, another principle is that highly redundant portions of a message handled via short-term memory should be entered last. Under these conditions the retention of the high information part of the message will not be disrupted, and overall accuracy and speed of entry will be improved. (See Conrad, 1958, and Shepard and Sheenan, 1965.)

Further evidence of the effect of short-term memory on data entry speed and accuracy indicates that the insertion of the easiest to remember (i.e., redundant) components of a message in the position most prone to error, according to short-term memory studies, is more efficient than the insertion of those easy components in any other position. The most crucial positions are those just following the middle of the message (Conrad, 1962b). (See Section 7.2.11.)

7.2.9 Chunking and Short-Term Memory

Direct evidence that people use short-term memory in the entry of telephonelike numbers is presented by Deininger (1960b and 1967) and Deininger et al. (1966). The timing of actual character-by-character entries indicates that all people divide longer messages into chunks which they then enter one chunk at a time from short-term memory. However, not all people choose the same chunks unless the messages are so formatted as to make a particular division highly persuasive. Furthermore, if the message length is near the limits of immediate memory span, e.g., about seven digits, then there are wide differences between people in terms of chunk size. Some people will store the entire message in short-term memory and enter it without referring back to the source, while others will chunk the message into at least two parts and refer back to the source between the entry of chunks. This difference in mode of entry makes for very large differences in entry rate.

7.2.10 Graphic and Pictorial Data Sources

Data entry will be faster and/or more accurate if the data to be entered contain information about the location or position of the response that is used to enter that data. For example, Leonard (1964) and Leonard and Newman (1965) report faster reaction times when there is a direct spatial or "geographic" correspondence between a stimulus light and the button which is to be touched in response to that light, than in the situation where the button to be touched is designated by a color, digit, or tone in a single centrally located stimulus cell. Other things equal, a "point-at" mode of entry is more accurate than a "type-in" mode. (See Earl and Goff, 1965.)

A series of papers, starting with Licklider (1960), call for graphic and, in some cases, speech input to data processing systems. These papers also call for outputs from the computer so that the operator and computer may actively interact in terms of all of the modes of communication which the operator would normally use. This active interaction would greatly facilitate human programming, problem solving, and designing capacities. (See Samuel, 1965; Siders, 1967; and Suppes, 1966.) Guiding principles for these modes of entry will evolve as these systems become more commonplace.

7.2.11 Recommendations for Input to the Operator

A faster entry rate with fewer errors depends on:

1. Order and clarity of source data;
2. Operator familiarity with a source's format;
3. For English text source data, a mixture of upper and lower case characters;
4. Division of long messages into chunks;
5. Clearly distinguishable source material;
6. High redundancy of source data for fast *character* entry rate, but minimum redundancy (high information per character) for fast *message* entry rate.

There is no consistent difference in data entry rate between the usual alphanumeric and straight numeric keypunching.

Messages composed of random sequences of just 10 of the possible alphabetic characters are not entered more rapidly or accurately than random sequences of all 26 characters.

The redundant portion of a message should be placed near the middle of the message in the source document. But the operator should enter that redundant portion at the end of the message. This apparently contradicts the recommendation that the sequence of source data corresponds to the sequence of data entered. The consistent sequence recommendation applies to sequences of "chunks" of a message, while this recommendation applies to sequences of characters within a "chunk," with the entire "chunk" being held in short-term memory.

Reducing the memory load requirements of the message should lead to more uniform modes of chunking and entering the data and more accurate and rapid entry.

Entry of graphically displayed data will be faster and more accurate if the data contain information concerning the spatial location or position of the corresponding act of entering that data. "Point at" entry is fast and accurate.

7.3 From Data Source to Data Entry

7.3.1 Translation, Encoding, and Chunking

Operators almost always encode source data into subjective units or "chunks" (Miller, 1956). These data are stored in short-term memory and entered by the human a chunk at a time rather than character-by-character or letter-by-letter. Whenever short-term memory is used, some form of encoding is involved.

Errors Reflect Chunking and/or Coding

In a study by Shepard and Sheenan (1965), all messages contained one of two redundant strings of four digits, along with four random digits. When errors were made in the redundant strings of digits they were frequently substitutions of one string of four for the other. When a redundant string followed the random digits, the interchange of redundant strings accounted for "60% of all incorrectly reproduced digits." Subjects handled these four-digit sequences as coherent psychological units or "chunks," and errors were not often made on characters within a chunk. Error analyses also suggest an *acoustic* encoding of *visually* or *tactually* presented messages (e.g., Conrad, 1963, 1964, 1966, and 1967). Thus, for data entry tasks with large short-term memory components, errors will tend to reflect chunk and/or acoustic confusions, and not, for example, aiming errors on the keyboard. (See Section 7.5.2.)

Encoding and Learning

The average size of subjectively encoded chunks grows with the learning or training of the operator in the particular data entry task. For example, the task of receiving Morse code

and translating it into typewriter output usually starts in a one letter at a time mode of reception, gradually progresses to the point where the operator recognizes common strings of letters and short words, and eventually, for the highly skilled operator, progresses to the point where entire phrases and/or short sentences are recognized as units (Fleishman et al., 1958; Fleishman and Fruchter, 1960; West, 1955 and 1962; Woodworth, 1938). This encoding proceeds almost without attention and direction if the operator is actively engaged in the task of data entry because the encoding makes the task easier. A similar effect has been noted for typing (West, 1957 and 1962; Woodworth, 1938). A clear laboratory demonstration of this effect is reported by Leonard and Newman, 1964.

7.3.2 Information, Encoding, and Motor Activity

Character entry rate is fast for highly redundant material (e. g., normal English text relative to random letters). Conversely, the higher the information per entry, the slower the rate of entries (where information is manipulated in terms of redundancy and/or the number of alternative characters). However, when measured in *information units* rather than number of entries data entry rate decreases with redundancy and increases with the amount of information per response.

The motor activity, such as keying, of a data entry operator appears to be slower than the encoding activity. Providing the operator with a system which requires less motor activity (e.g., keystrokes) per unit of information permits the the operator to increase the overall rate of information entry. The price paid for the increased information entry rate is usually in terms of the time required to train the operator on the coding scheme, and on the special motor responses that usually go along with entering it.

The extent of on-the-job training depends upon the form of the data entry task and the material being entered. For example, if the operator's output is in a highly familiar form (e.g., reading aloud), he is almost immediately able to take advantage of the well-known redundancies in English text.

Information, Rate of Entry, Practice, and Compatibility

While entries per unit time generally decrease as the amount of information per entry increases, practice in the task generally reduces the slope of this functional relationship toward zero. That is to say, with sufficient practice (or familiarity) there is essentially no slowing down of rate of entries with increases in information per entry (Conrad, 1962a). In a similar manner, highly compatible stimulus-response relationships also lead to a slope close to zero.

7.3.3 Distribution of Errors, Discrimination, Confusions, and Information Transmitted

Difficulties in discrimination of the stimuli to be entered or the confusions among responses to be made lead to unequal distributions of operator errors. Seibel (1963a), for example, gives a formula for calculating the minimum possible transmission of information for given error rates and numbers of equally likely stimuli. In a particular example, for 1023 stimulus alternatives and a probability of error equal to 0.1, the minimum information transmission by the operator is equal to 8.53 bits (all errors equally likely, and randomly spread among all stimuli). The maximum transmission figure (only one kind of error, and always associated with one stimulus) for the same conditions is just slightly below 10.00 bits. Thus, for these conditions, the difference in the distribution of errors can lead to a difference of as much as 1.47 bits of information transmitted with each response. Clearly the distribution of errors resulting from discriminability of stimuli and/or confusions among responses must be taken into account in establishing any relationship between response time and information transmitted per response.

7.3.4 Other Factors

Motor Difficulty of Entries

Motor difficulty leads to slower responding, more variable response times, and more extensive changes in both time and variability as practice progresses (Seibel 1962b, 1962c, and 1963a). Furthermore, when mixed with easier

responses, difficult motor responses produce more variable response times than would be obtained for the difficult responses in isolation. The converse is also true. That is, easier responses mixed with more difficult ones will tend to yield less variable response times than would those easy responses in isolation. Average response times for easier responses also tend to be faster in isolation than if the easy responses are mixed with difficult ones. Error rates also tend to be higher for an isolated set of easy responses, and lower for an isolated set of difficult responses, than would be obtained when the easy and difficult responses are intermixed. Clearly the motor difficulty of the particular responses cannot be ignored in designing data entry devices. See Conrad and Longman (1965) for further evidence in a typing-like task.

Speeded Production vs. Daily Production

For short speed tests of one-half hour, speed on the card punch averages more than 5 strokes per sec. on jobs with no complication (Klemmer and Lockhead, 1960 and 1962a). Over a working day an average of 2.8 strokes per sec. will be achieved during time actually spent on the machine. Thus, there is almost a 2:1 difference in data entry rate when operators are primed for taking a "speed test."

A similar effect s reported for typists. The average typist in a 5-min. speed test will gross about 70 w.p.m. For a full day's typing the standard manuals ask for an average of approximately 35 w.p.m. (a word is equivalent to five strokes, four characters plus space).

Typing is somewhat faster than key punching according to these figures, but there is still a marked difference between daily production rate and speed test rate. Since typing tasks usually involve the entry of highly redundant English text, whereas keypunching tasks quite frequently involve material with much less redundancy, and since the typing test is only 5 min. long, the apparent difference in speed between typing and keypunching may be misleading. (See Section 7.5.1.)

Speed vs. Accuracy

Operators can be induced to exchange speed for accuracy by means of instructions, punishments, and differential pay-offs (e.g., Fitts, 1966). However, if speed stress is pushed beyond the point of achieving reasonable accuracy, performance in terms of rate of information transmission deteriorates rapidly. A similar deterioration occurs with excessive stress on accuracy (Hillix and Coburn, 1961). Experienced data entry operators work at a near optimum (for them) compromise between speed and accuracy.

Machine Lag, Delay, and Pacing

The effects of mechanically slowing down the operator, pacing the entries, or limiting the speed of entry, are also factors in data entry device design.

Delay reduces advantage of redundancy. Leonard (1958) reports that a 0.35-sec. delay (between the presentation of a stimulus and the time when the equipment would accept a response) had only a slight effect on a five-choice equiprobable discrimination reaction time task. However, when there were four equiprobable alternatives and a fifth alternative occurring 8.5 times more frequently than others, this redundant or biased input permitted markedly faster performance with no delay, but only slightly faster performance with enforced delay.

Delay reduces speed of letter sorting. Conrad (1960c) studied the distributions of operator response times on a Post Office letter sorting system. Performance continued to show improvement for a full year on the job following initial training ("Effects of Training and Time on the Job" in Section 7.5.2), with sorting rate showing a growth from approximately 36 sorts per min. to almost 60 sorts per min. The sorting system enforced a 0.55-sec. delay after each sorting response. The sorting rates are production figures, to be contrasted with sorting speeds obtained during 20-min. speed tests for which sorting rates were usually about 10 sorts per min. higher.

Examination of the distribution of actual sorting times was made for performance at the end of the year of practice. Distributions were sharply "L" shaped, with from 65% to 85% of all response times falling between the mean time and the lower limit of 0.55 sec. The mean response time for all operators was 0.88 sec. Thus,

the operators had adapted to the enforced lag and were making the vast majority of their responses fall within 0.3 sec. of the minimum possible time intervals.

Utilizing the distribution observed, significantly faster sorting times are *estimated* for the unpaced condition with no artificial lag. Estimates of sorting rate show a steady decline with increases in duration of lag.

Machine pacing reduces speed of letter sorting. Estimates of sorting rate under machine-paced conditions in the Conrad (1960c) study show a maximum for a pacing rate of approximately 75 sorts per min., but this rate is still considerably below some of those actually obtained and far below those estimated for the unpaced situation. It is important to note that the sorting rates are estimates, and Conrad cautions that the assumptions under which they are made may not be entirely correct.

Conrad concludes that

> In general it seems clear that unpaced letter sorting machines ought to give a higher output than machines which either have a minimum time between one response and the next, or which are paced; the difference being fairly considerable. Where the choice is between a lag and a fixed pace, the acceptable values of each must be taken into account. But whereas reducing the lag will always increase output, increasing the rate of pacing may lead to a drop in output.

Delay reduces speed of typewriting. Minor (1964) reports on an enforced lag (an interlock system) for a typewriting task. Operators typed lists of names and addresses with each having a five-digit random number with it. The longer interlock system required 0.125 sec. between keystrokes, thus setting a typing rate ceiling of eight characters per second; the other 0.077 sec. and 13 characters per sec. Operators were still learning to adapt to the interlock systems at the end of the study, but at that time the shorter interlock condition led to approximately 42.1 w.p.m., while the longer led to only 40.3 w.p.m. (difference significant at .05 level). Total errors (detected and corrected, plus undetected) were not significantly different from each other for the two conditions, but there was a slightly greater number of total errors for the longer interlock condition. The proportion of keystrokes which were undetected errors was significantly (0.05-level) smaller for the longer interlock condition; the magnitude of the effect was approximately 15 versus 18 undetected errors per 10,000 strokes. Thus, the shorter interlock condition led to approximately 4% greater output per unit of time, a slightly lower overall error rate, but approximately three strokes in 10,000 greater undetected errors.

Operators reported that only infrequently, if at all, did they "run" into the interlock during the test period. This suggests that

> Differences in typing speed and error rates were the results of self-imposed pacing rather than a function of 'running' into interlocks. The study does not justify generalizing that longer interdigital interlock time always generates greater accuracy. In all probability the effects of different interlocks will vary as a function of key force displacement characteristics, the nature of the input material, and the skill level of the typists.

The typing of more highly redundant material would be expected to lead to a greater frequency of very short inter-keystroke times, and thus a greater debilitating effect for the long interlock condition. (See "Keystroke Timing and Key Interlocks," in Section 7.5.2.)

Continuous vs. Discrete Tasks

Another important general variable affecting data entry has to do with the fact that each entry is one of a continuous flow of entries. The operator continuously takes in and processes source data while emitting a sequence of entry responses.

In general, if the operator has the opportunity to acquire information from the source, process it, and form it into familiar sequences of entry motions, he can overlap these activities in time and take maximum advantage of the redundancy in the source (see Section 7.2.8, "Redundancy of Input"); *and* in the *sequence* of entry *movements.* A continuous data entry task apparently involves a sort of running short-term memory component as well as chunking. For non-redundant material, e.g., random strings of letters, the running memory (when coupled with the chunking and responding) is approximately three letters long. For normal English text, however, the length of the running memory component appears to have no clear-cut and obvious upper bound. (See Hershman and Hillix,

1965; Leonard and Newman, 1965; Poulton, 1958.)

The effects of the difference between discrete and continuous tasks on various functional relationships (e.g., rate of information entry as a function of information per entry, entry rate as a function of practice, information rate as a func- of practice, entry rate as a function of compatibility, etc.) have yet to be evaluated.

Error Detection Overlaps Other Data Entry Activity

Further indication that overlapping activities take place during a data entry task is provided by Rabbitt (1967). Digits were projected, one at a time, with a new digit appearing within 20 msec. of a correct key press response. Whenever a subject detected that he had made an error, he was to immediately depress a pair of error keys. Intervals between stimuli and correct responses (CRT) were recorded. Reaction times between an error response and the response signaling a detected error (EDRT) were also measured. At the end of practice a series of experimental conditions (degree of compatibility, number of alternative stimuli, number of alternative responses) produced differences in CRT's, but not in EDRT's. Error rates were generally between 3% and 5% at the end of practice, and from 86% to 90% of all errors were detected. Error detection is clearly not the same process as is the making of a correct response, but obviously some form of response checking must take place concurrently with the usual data entry activity.

Encoding to Increase Information Entry Rate

The act of encoding during a data entry task need not slow down the rate of data entry in keystrokes and/or bits. In the usual data entry task, encoding and entry overlap in time. Thus, there is an advantage in the data entry situation in which the operator can encode a redundant source message to reduce the redundancy in the sequence of data entry motions, i.e., reduce the actual number of data entry motions. Several chord keystroke systems employ this principle (Section 7.4.3. contains additional details).

Letter-sorting. Perhaps the best known are the coding systems developed and evaluated for the sorting of mail (Cornog and Craig, 1965). While no careful experimental comparisons have appeared in the open literature, various codes have been described and representative performance data have been discussed at professionsal meetings (Cornog et al., 1963).

In general, mail can be sorted, using a variety of different extraction codes and a straight memory code, with a variety of keyboards. Comparisons are difficult to make on the basis of the reported information, but it is clear that a variety of different encoding and keyboard combinations *do work.*

"Rapid-type" system. Similar demonstration-like data are reported by Seibel (1962a) for a "Rapid-type" data entry system. Operators learned to encode by substituting special abbreviations for frequently occurring strings of letters in normal English text. The abbreviations were introduced gradually and performance showed little decrement resulting from the added encoding burden. With additional practice, performance showed continuous improvement. The letter sequences to which abbreviations were assigned were derived from studies of letter-sequence frequencies (e.g., Seibel, 1963b).

Eight-key chord keyboard. In still another demonstration (Lockhead and Klemmer, 1959), operators were taught to use an eight-key chord keyboard to enter 100 common words (each with a single chord-keypress), the 35 alphanumeric characters, and two punctuation marks. After training, subjects utilized word encodings almost without exception when they were given the option of doing so, or of entering words character-by-character. The 137 chord patterns used were learned in less than 30 hours. Word patterns were entered at between 36 and 55 w.p.m.

Stenotyping system. While the stenotyping or court steno-writing systems require extensive practice to achieve acceptable steno-writing entry rates, the *minimum* expected rate for proficient operators is equal to or better than the world championship typing rate (Seibel, 1964a). The steno-typist, at 200 w.p.m. is estimated to be entering approximately 3 chord-keystrokes per sec., with between 11 and 16.7 bits per stroke, while a "very good" typist at 100 w.p.m. is entering approximately 8.3 single keystrokes per sec., with 2 to 3 bits per stroke. Thus, the typist is keying almost three times as many entries per sec., but entering information at approximately one-half the rate (for the example figures used) of the steno-typist.

Thus, anecdotal and demonstration data suggest that the encoding aspect of the task may call for additional training time, but once high levels of proficiency are attained, the data entry rate in information units or in number of messages entered, is higher than would be attained with character-by-character data entry by a conventional typewriter keyboard.

Experiments with Redundancy-Reducing Codes

Two experiments (Tirrell and Klemmer, 1962; and Deininger, et al., 1968) have examined the effects of redundancy-reducing codes utilizing single-character-per-stroke keyboards (i.e., standard typewriter) or single-character-at-a-time handwritten entry. Entry rates achieved with the coding were better than those without the coding, but the advantage was not as impressive as some of the demonstrations, or stenotyping, would lead one to expect. The impressive gains in data entry rate appear to result from a combination of message encoding and keystroke encoding, such that each single keystroke (usually a chord keystroke) carries a great deal of information. Some of the factors and trade offs involved in developing a specific system to incorporate these principles are discussed by Seibel 1964a). Experimental data are sorely needed.

Corrections, Editing, and On-Line Problem Solving

The more directly the operator can attend to the task at hand, the more efficient will be his operation. Distracting machine demands, such as specific formats, margins, unique spatial locations, special and unusual symbols, cumbersome correction procedures, etc., should be avoided if at all possible. If the important job of the operator is editing, or writing, or designing, or programming, etc., and a large and expensive system is being committed to facilitate his performance of that job, then it makes no sense to distract him from doing his important work by imposing machine-idiosyncratic data entry demands in order to save relatively trivial dollars in engineering or software costs. Unfortunately there are no experimental data for guidance in this area. What support there is for the general principle must be derived from an examination of "what sells."

7.3.5 Recommendations

Translations Requirements

In designing any data entry task, consider that the operator encodes the source data into subjective units or "chunks." Source data formats should be designed with this characteristic in mind. When short-term memory is utilized by the operator, the errors made will tend to reflect confusion among the *encoded* forms of the source data.

The size of subjectively encoded chunks grows with the experience of the operator in the particlar data entry task. This principle should be considered in source data, task, and data entry device design.

New forms of encoding may be learned rapidly if the code takes full advantage of prior learning, e.g., the redundancies of normal English text.

The motor activity of the data entry operator is slower than the encoding activity. Giving the operator a system which requires less motor activity (e.g., keystrokes) per unit of information allows the skilled operator to increase overall rate of information entry. There appears to be little or no overall reduction in entry rate with increases in information per entry for the skilled operator.

Other Factors

Discriminability among the elements in the source data, and in their encoded equivalents, has an important effect on the distribution of operator errors. Discriminability amongst the data entry motions has similar effects. More difficult discriminations lead to higher error rates. Particular confusions lead to particular errors, and these factors should be taken into account in design considerations.

The motor difficulty experienced by the operator in effecting particular entries influences overall rate of entry, error rate, and variability in the time intervals between successive entries. Awkward reaches on the standard typewriter keyboard, and particular chords on a chord keyboard, are more difficult than other strokes on the same devices.

The stage of learning for a given set of operators on given data entry tasks has a very large effect on the performance on that task. Rate of

improvement clearly depends upon the motor difficulty of the task; upon discriminability of the message units, encoded message units, and responses; upon the redundancy of the source material, etc. This creates difficult practical and theoretical problems for comparing skilled entry rates for different data entry tasks and devices. Effective elimination of stage of learning as a confounding variable requires very extended periods of practice (at least six months, often a year or more) such that performance shows little or no further improvement with still more practice. (See Section 7.5.2, "Effects of Training and Time on the Job", for further consideration.)

Information entry rate is approximately constant, and maximum, only over a very limited range of speed and error trade off, with a sharp drop outside of the range. Pushing response speed above the optimum range leads to marked increases in error rate (so called "information overload") and the rate of information entered drops off. Excessive attention to accuracy leads to marked reductions in entry rate, but only slight reductions in error rate, with a consequent sharp reduction in rate of information entered.

There are optimum pacing rates for many tasks, but optimum paced rates yield performance considerably below that which the operator can achieve under unpaced conditions. Machine pacing should *not* be used to manipulate incentive.

Interlocks on keyboards introduce a lag between successive entries. Generally, interlocks degrade performance, but they *may* lead to a slightly better rate of self-detection of errors. Operators "adjust" to enforced lags by slowing down their most rapid response sequences.

Encoding to Increase Information Entry Rate

The act of encoding during a data entry task need not slow down the rate of data entry (in keystrokes and/or bits), if the operator is permitted to preview the source material and overlap in time his encoding and output motor activities. Simple encoding schemes, familiarity with material and encoding, and practice, all contribute to faster encoding activity. If encoding and motor activities can fully overlap in time, motor activities will not be slowed down by the encoding.

Information entry rate is higher for tasks with the greater amount of information per entry. This is true even if the operator is not able to preview the source data.

Given the opportunity to preview and encode redundant source data so as to reduce the redundancy in the sequence of data entry motions, (i.e., further increase information per entry), still higher information entry rates should be possible. This inference has led to the development of several data entry systems, e.g., codes and keyboards for sorting mail, "Rapid-type," an eight-key chord keyboard, etc.

Data Entry by On-line Problem Solvers

The editor, designer, programmer, etc. should not be distracted by machine specific details such as special formats, margins, unusual symbols, cumbersome correction and insertion procedures, etc.

7.4 Data Entry Devices

7.4.1 Alphanumeric Keyboards

The arrangement for the alphabetic keys, and the digits 2 through 9 and 0, on typewriters was set by tradition nearly a century ago. There are probably more than 10,000,000 typewriters in the United States with keys arranged in this traditional way. The arrangement is known as the "Sholes" or "QWERTY" arrangement. Despite demonstrated advantages for other arrangements the overall economics and retraining aspects of the situation strongly suggest that the QWERTY arrangement be considered *the standard.*

More efficient keyboard arrangements (e.g., Dvorak, 1943; Griffith, 1949) can be recommended *only* in those cases where there is rapid and complete interchangeability possible at relatively low cost. Complete interchangeability must include changes in key top designations, the characters controlled by each key, and in the case of keyboards producing encoded output for data storage or entry, the interchangeability must also include the encoding system. This complete interchangeability is not readily available in the current market place. No data are available to give reliable guidance as to the

expected magnitude of advantage in daily production (as distinguished from speed-test performance) for more efficient keyboard arrangements. Obtaining these data would require lengthy and expensive experimentation. Without the information, it is impossible for the system designer to trade off equipment cost (in order to achieve interchangeability) with system throughput. A *guess* would set the *upper limit* of the daily production advantage for the modified keyboard arrangements at about 10%.

Standard Code

For electronic data processing systems, each character and function key on the alphanumeric keyboard must be assigned a unique bit pattern or code. A standard code, the American Standard Code for information Interchange (ASCII), has been adopted as a standard code for all U.S. Government users. It specifies 95 graphic characters and 33 different function messages. It is a seven-bit code and is fully described in Figure 7-1. Obviously, it should be considered *the standard.*

Special Characters and Bit-Pairing

Since bit configurations are specified for all of the characters in the ASCII code, these configurations were used for determining the arrangement of the keys on a proposed standard keyboard. Upper and lower case equivalent characters were arranged on the keys so that any upper case character differed from its lower case version only in terms of the value for a single bit ("one" for lower case and "zero" for shift). Thus the action of the shift key was supposedly simplified for the engineering of the keyboard. The characters so arranged are said to be "bit-paired." The resultant keyboard arrangement is depicted in Figure 7-2. The arrangement includes seven keys which are exceptions to the simple "bit-paired" shift action (reversals of normal action for bit five for four keys, for bit six for one key, and no effect for two keys; see Standards, 1968a, for details). Despite this "simplicity," engineering convenience is still cited as the reason for maintaining the bit-paired character arrangement on the keyboard.

The most common arrangement for the characters of the alphanumeric keyboard is illustrated in Figure 7-3a, the 1966 suggested "preferred arrangement" for the electric typewriter keyboard. Discrepancies between this arrangement and the one proposed in Figure 7-2 are highlighted in Figure 7-2 by shading. The locations for 14 special characters are involved. Highly skilled touch typists will be seriously inconvenienced by the rearrangement of these special characters.

Other arrangements for "typical" teletypewriter and manual typewriter keyboards are shown in Figures 7-3b and 7-3c.

Training Consideration and a Recommendation

If data entry terminals incorporate a character arrangement different from the electric typewriter, the data-processing industry is imposing a penalty on itself in terms of retraining, interchangeability of equipment, and reduced throughput if the same operator is to switch back and forth from a typewriter to a data entry terminal. The equipment cost for offsetting this penalty calls for special bit-code generation for approximately one dozen keys on the keyboard, particularly with respect to the upper case version of the characters on those keys. Approximately half of those keys are among the keys calling for exceptions to the simple bit-paired shift action. All things considered, it is strongly recommended that the arrangement of the special characters conform to that suggested for the electric typewriter (e.g., Figure 7-3a), and the burden of character-to-code translation be placed on the electro mechanical design of the keyboard rather than on the data entry operator.

Card Punches

The punched card and card-punch machine (i.e., the "keypunch") are the current major forms for data entry. Particular system requirements must be taken into account in deciding on the relative advantages or disadvantages of the "unit record" feature of the punched card. For typical high volume entry, however, the punched card appears to have little if any advantage.

Keyboard to Magnet Tape (or Disc)

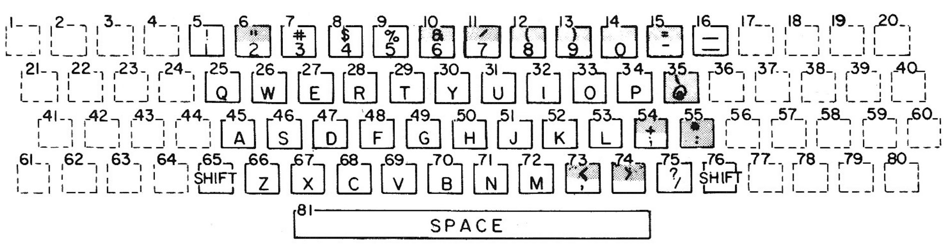
One current innovation, rapidly growing in popularity, permits data entry via a typewriter-

b4	b3	b2	b1	ROW \ COLUMN	0 (b7 b6 b5 = 0 0 0)	1 (0 0 1)	2 (0 1 0)	3 (0 1 1)	4 (1 0 0)	5 (1 0 1)	6 (1 1 0)	7 (1 1 1)
0	0	0	0	0	NUL	DLE	SP	0	@	\	P	p
0	0	0	1	1	SOH	DC1	!	1	A	a	Q	q
0	0	1	0	2	STX	DC2	"	2	B	b	R	r
0	0	1	1	3	EXT	DC3	#	3	C	c	S	s
0	1	0	0	4	EOT	DC4	$	4	D	d	T	t
0	1	0	1	5	ENQ	NAK	%	5	E	e	U	u
0	1	1	0	6	ACK	SYN	&	6	F	f	V	v
0	1	1	1	7	BEL	ETB	'	7	G	g	W	w
1	0	0	0	8	BS	CAN	(	8	H	h	X	x
1	0	0	1	9	HT	EM	)	9	I	i	Y	y
1	0	1	0	10	LF	SUB	*	:	J	j	Z	z
1	0	1	1	11	VT	ESC	+	;	K	k	[	{
1	1	0	0	12	FF	FS	,	<	L	l	\	¦
1	1	0	1	13	CR	GS	—	=	M	m	]	}
1	1	1	0	14	SO	RS	.	>	N	n	^	~
1	1	1	1	15	SI	US	/	?	O	o	—	DEL

■ CHARACTERS FOR WHICH SPECIFIC KEY LOCATIONS ARE NOT PRESCRIBED

░ EXCEPTION TO SIMPLE SHIFT ON ASCII KEYBOARD

FIGURE 7–1. USA Standard Code for Information Interchange (ASCII) per USAX 3.4–1967 as published in Standards (1968a).



NOTES:

1. The key position numbers are intended for reference purposes only.
2. The alphabetic symbols represent the lowercase letters as well as the uppercase letters.
3. The area in which the graphic keys are placed corresponds to the so-called "44-key touch-typing area."
4. Positions shown by broken lines appear for reference purposes only. Characters are not assigned to them in this standard but may be in subsequent standards.
5. Shaded symbols disagree with those proposed as a preferred arrangement for electric typewriters in 1966 (see Figure 7-3a).

FIGURE 7–2. Proposed USA Standard general purpose alphanumeric keyboard arrangement for information interchange (USASI Document X4/35. X4–A9/54, X4–A9.1/160, July 10, 1967), as published in Standards (1968a).

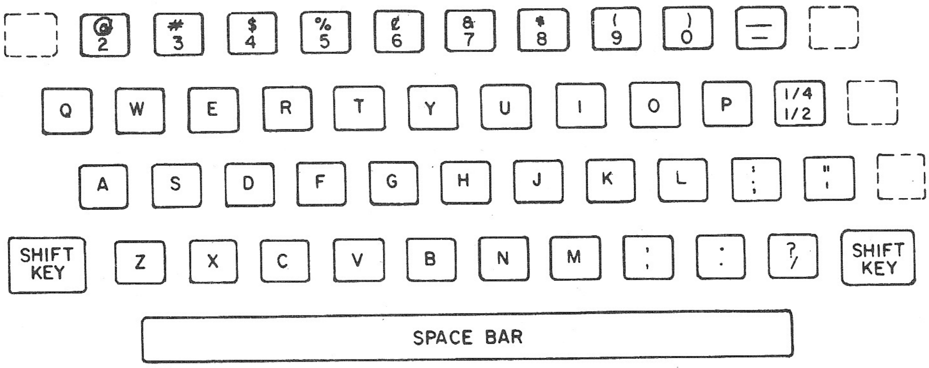


FIGURE 7–3a. Electric typewriter arrangement (preferred arrangement) as published in Standards, (1968a).

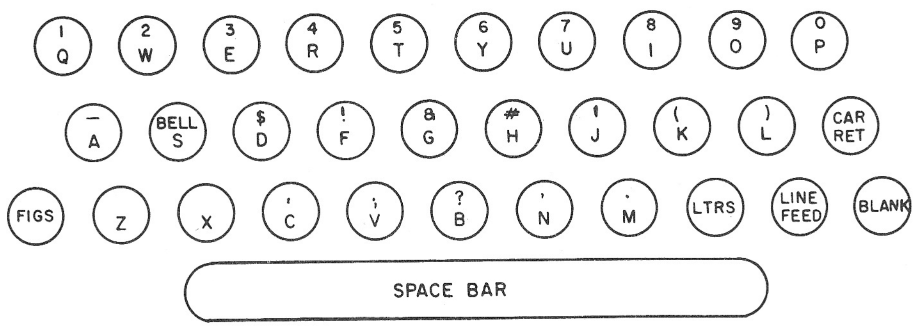


FIGURE 7–3b. Typical three-row teleprinter keyboard as published in Standards (1968a).

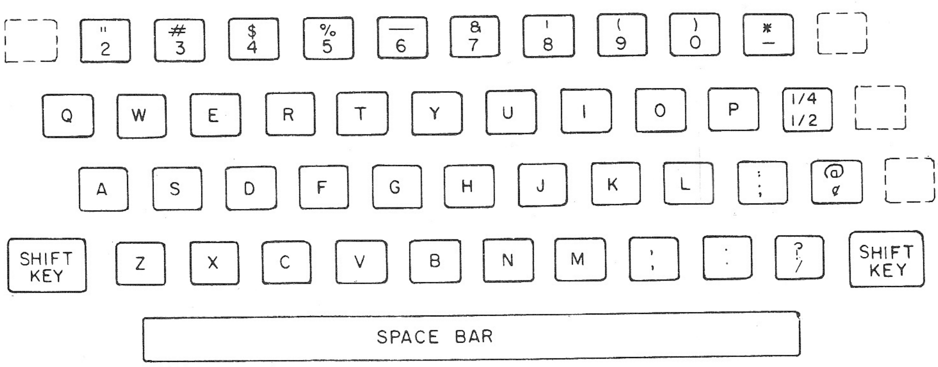


FIGURE 7–3c. Manual typewriter keyboard alternate arrangement, as published in Standards (1968a).

like keyboard and records the information directly on a magnetic tape (or disc). These systems permit the effective utilization of typists, rather than specially trained keypunch operators. They may also permit easier self-detection of errors, easier correction of error, simpler verification of data, and record lengths greater than 80 characters.

Typewriter and Character Reader

Another alternative for data entry incorporates the ordinary typewriter (perhaps with special type font) and an optical character reader. (See Section 7.4.11, "Character Readers," for details.)

Typewriter to Punched Paper Tape

Another important form of data entry utilizes a typewriter like device to simultaneously generate typed output and punched paper tape. These systems are usually less expensive, and permit endless record length. They do not offer easy insertion and removal of units of data, error correction is awkward, and speed of reading into data processing systems is slower than magnetic tape (or disc).

Choosing an Alphanumeric Data Entry Subsystem

Choices amongst these data entry subsystems must take into account the economic aspects of equipment costs themselves as well as human factors considerations, e.g.: (a) ease of self-detected error correction, (b) verification procedures, (c) ability to insert or delete parts of a message, and (d) utilization of pre-job typing training, etc. There are no data for guidance in estimating the many trade off functions involved. (See Section 7.6, "Factors in Selecting Data Entry Systems," for further considerations.)

7.4.2 Numeric Keyboard

Full Matrix vs Ten-Key Keyboard

There are two major ways of arranging keys for numeric data entry. The first is the full matrix keyboard with ten or more columns of keys and each column containing a key for each of the digits 0 through 9. The second is the ten-key keyboard containing just one key for each of the ten digits arranged in a three-by-three matrix, with the zero key either above or below the others.

Since the ten-key arrangement is the only one of the two which permits "touch" operation, there is no question at all concerning a choice between the two for high-volume, production data entry. Minor and Revesman (1962) compared the two for a non-touch data entry task where entries were made relatively infrequently by unskilled keyboard operators. The ten-key arrangement was provided with complete visual indication to the operator of the digits entered (some versions of the ten-key arrangement only provide indication of the number of digits entered). The ten-key arrangement was clearly superior to the full matrix, even for occasional entry by unskilled operators. However, if the ten-key arrangement does not provide complete indication of the digits entered, it *may* not be superior for this kind of task--there are no published data.

Ten-Key Digit Arrangements

There are many digit arrangements possible on a ten-key keyboard. Though many have been explored (Deininger, 1960a, 1960b; Lutz and Chapanis, 1955), only two have been in serious competition with one another. A third, frequently used, arrangement is the two-handed touch operation of the digit keys along the top row of the typewriter keyboard, though no comparison data are available for it in a production-like situation. The two-handed touch operation suggests that it *may* be superior for certain kinds of production tasks. Of the two arrangements currently "in competition," one has the digits 1, 2, and 3 in the top row, with 7, 8, and 9 in the bottom row. This arrangement will be referred to as the "123" arrangement and is found on the common keypunch machine. The other arrangement has the digits 7, 8, and 9 in the top row, with the digits 1, 2, and 3 in the bottom row. This latter arrangement is to be found on common adding machines and will be referred to as the "789" arrangement.

There is little question that the highly practiced data entry operator will perform about equally well with either the 123 or the 789

arrangement. The difference in arrangement becomes critical for the operator who only makes occasional entries, and for the operator who must alternate between different arrangements. Lutz and Chapanis (1955) report that people "expect to find" the 123 arrangement, with the frequency of expectation about five times higher than it is for the 789 arrangement.

Conrad and Hull (1968) compared performance on the two arrangements utilizing housewives as subjects. One group performed with the 123 arrangement, a second group with the 789 arrangement, and a third group frequently alternated between the two arrangements. The 123 group performed slightly faster and significantly more accurately than the 789 group, and both groups performed markedly better than the group that alternated. Entry rates were approximately 1 sec. per digit with error rates approximately 1% or less. Minor and Revesman (1962) report similar entry rates for production workers.

In a study utilizing Post Office clerks, Conrad (1967) reports 0.67 sec. per stroke for the 123 arrangment, with an error rate of 0.55%; the rate of entry for the 789 arrangement was 0.73 sec. per stroke with 1.16% wrong keystrokes. Paul et al., (1965) also report advantage for the 123 arrangement, using air traffic controllers as subjects.

Thus, three different populations of subjects all yield the same conclusion: namely, the 123 arrangement is both faster and more accurate than the 789 arrangement for the relatively unskilled operator.

Since push-button telephones are utilizing the 123 arrangement, all operators may be expected to be familiar with it in the not too distant future. The alternation group of housewives in the Conrad and Hull study points up the disadvantage of expecting operators to alternate between the two arrangements. Thus, the recommendation is made that the adding machine arrangement, i.e., the 789 arrangement, be changed to conform to the telephone and keypunch arrangement: the 123 arrangement. The 123 arrangement is recommended as a standard.

Zero-Key Location on Ten-Key Keyboards

Data relative to the location of the zero key on ten-key keyboards are not easily interpreted. Lutz and Chapanis (1955) report a slightly greater expectation for the zero following the nine rather than preceding the one, but performance data in actual data entry tasks are not available. The keypunch places the zero key above the three key, while the ten-key telephone arrangement places the zero key below the eight key. Performance data in controlled experiments are needed before a firm recommendation can be made.

7.4.3 Chord Keystrokes

Early Work

In 1958 Klemmer trained two subjects to type alphabetic characters on a special ten-key keyboard. There was a key for each of the ten fingers, and each alphabetic character was represented by the simultaneous depression of 2 of the 10 keys. Klemmer concluded that entry speeds were "not out of line with performance in learning to type on a conventional machine." He noted that people were capable of pressing multiple keys almost simultaneously (within 0.03 sec.). Klemmer's work represents the beginning of the investigation of chord keystrokes for for producing correctly spelled English output.

Lockhead and Klemmer (1959) examined an eight-key chord keyboard system for the entry of data. One or two keys per chord were utilized for entering the alphanumeric characters, while chords of from three through seven keys were used to represent 100 common English words. Approximately 23 hours were required to learn chords corresponding to the 100 words and the alphanumeric charactrs.

The 31 Chords of One Hand

Ratz and Richie (1961) and Seibel (1962b) studied the 31 chords possible with the five fingers of one hand, and report very similar rank orderings of the difficulties of those chords. Single key responses are the fastest, but for chords involving two or more keys it is necessray to consider the specific pattern of keys in order to assess the difficulty of the chord. Table 7-1 presents the chords, associated discrimination reaction times (DRT), and error percentages for the highly practiced subjects in the Seibel study.

TABLE 7–1. AVERAGE DRT'S AND PERCENTAGES OF ERROR FOR EACH OF THE 31 PATTERNS

Pattern* (1 2 3 4 5)	DRT (msec)	Error (%)
4	281	5.9
3	285	2.4
1	289	1.8
2	292	5.0
5	294	5.6
1 4	306	3.8
2 3	306	8.8
3 4	306	10.3
1 2	310	6.2
2 3 4	311	9.1
1 3	312	5.0
1 2 3 4	314	4.1
1 2 3	315	5.3
1 5	315	5.6
4 5	316	11.5
2 4	316	12.1
2 3 4 5	317	4.4
1 3 4	320	10.6
3 4 5	321	7.6
1 2 3 4 5	325	7.4
2 5	326	12.4
1 4 5	328	8.2
1 2 4	328	13.2
1 3 4 5	330	12.4
1 2 5	335	11.8
3 5	343	13.2
1 2 3 5	345	18.8
1 3 5	349	15.0
2 4 5	349	20.9
1 2 4 5	351	25.9
2 3 5	352	22.1

Seibel (1962b).
*1 = thumb; 5 = small finger.

It is difficult for the subject to manipulate his fingers to strike some of the 31 chords.

Reaction Time and Number of Different Chords

If the effect of motor difficulty is balanced out, the number of alternative chords involved in a given reaction time task makes little or no difference in the reaction time for numbers of alternatives from 5 through 31 (Seibel, 1962c). The overall average motor difficulty of a set of responses, however, does influence the reaction times for the specific chord responses in the set.

The lack of dependence of reaction time on the number of alternative responses is further emphasized in a report by Seibel (1963a) in which reaction times for 1,023 alternatives are only approximately 25 msec. slower than the reaction times for 31 alternatives, and part of this small difference is attributable to the fact that the larger set contained more difficult chord patterns.

Thus, laboratory data support what is obvious from listening to a piano concert: humans can simultaneously strike several keys in a keyboard and produce a chord. The laboratory data also indicate:

1. That practiced subjects can strike chords within 0.3 to 0.4 sec. after being shown which chord to strike;
2. The relative difficulties of the chords of one hand;
3. Simultaneity can mean less than 30 msec.;
4. The number of different chords (beyond five or so) has little or no effect on speed of response for practiced subjects.

Chord Keystrokes on a Modified Typewriter

Seibel (1962a) reports on a practical system for utilizing chord keystrokes on a modified standard typewriter with two extra shift keys. The system was designed to utilize trained typists who could continue productive work while learning to utilize the additional advantage of the special chord keystroking. The system utilized chord strokes to stand for commonly occurring words, phrases, prefixes, and/or suffixes. Lists of these abbreviations could be entered at from 100 to 120 chord entries per min. This is almost twice the rate reported by Lockhead and Klemmer (1959) for their eight-key word-writing system. The *demonstration* data suggest data entry rates one and one-half times standard typing rates with only 150 special chords.

Mailsorting by Chord Keystroke

The major use of chord keystroke data entry has been in systems designed to facilitate letter sorting in Post Offices in Canada, England, and the United States.

Conrad (1960b and 1960c) reports on a letter-sorting machine involving simultaneous depression of two keys (one for each hand) in order to sort letters into 1 out of 144 possible destinations. Each hand had one of 12 keys to select (arranged in two rows of six keys each). The machine was limited to approximately 110 letter sorts per min., i.e., approximately 0.55 sec. between sorts. After nine months of practice, letter-sorting performance was examined in terms of times between successive chord entries. Most times

were close to the 0.55 sec. machine limitation. Sorting rate proceeded from approximately 35 sorts per min. to about 60 sorts per min. over the practice period.

Cornog et al. (1963) and Cornog and Craig (1965) report on various chord keyboards and coding schemes utilized by the U.S. Post Office. Some representative speeds and error rates are presented for one of the keyboards and codes, but no experimental data are reported.

Conrad and Longman (1965) report on a direct experimental comparison of a chord keyboard versus a standard typewriter keyboard for the sorting of mail by postmen who were naive with respect to the use of a typewriter. The keyboard called for the simultaneous (within 0.05 sec.) depression of two keys for each chord, one key affected by each hand. There was a logical sequential pairing of the alphabet to the chords. Postman were trained for 3.5 hours per day, five days per week, for approximately seven weeks. One group was taught to encode mail for sorting while using the chord keyboard while another was taught to do so using the standard typewriter keyboard.

At the end of 33 days of total training, the chord keyboard class was entering an average of approximately 98 strokes per min., about 6 key strokes per min. faster than the average of the typewriter class. The superiority of the chord keyboard was present despite the lack of immediate feedback for operators utilizing the chord system, while operators of the typewriter system did get immediate feedback with respect to what they had keyed. However, the typists were more accurate at the end of practice (10% verus 20% error rate). Only about 1% of the chord keystrokes were in error due to lack of simultaneity.

The chord keyboard system appears to have decided advantages in cases where the operator population has no typewriter training prior to the job though the opposite might be true if the operator population were trained to type prior to starting their job. In contrast, the system described by Seibel (1962a) is specifically designed to take advantage of prior typewriter training.

Stenotyping

An attempt to utilize the phonetically encoded stenotyping system for data entry is described by Galli (1960). A modified Stenotype keyboard was used to feed modified Stenocode into a computer for translation. No experimental data are reported. Drawbacks to the system are related to the extensive training period to learn the modified Stenotype code, and the extensive and sophisticated computer and computer program necessary to translate the somewhat ambiguous phonetic code into correctly spelled English text.

Application and Potential of Chord Keyboards

A variety of keyboards and coding systems have been developed for letter sorting. None stands out as significantly better than others, so far as the published experimental literature reports. There are no other commercially available chord keyboards for data entry.

The potential of chord keyboard data entry is very high. Indications are that entry rates of 150% of standard typing are relatively easy to achieve. It is recommended that chord keyboard systems be explored more fully for data entry purposes, especially in systems where small special-purpose digital computers can be linked with the keyborads to effect immediate translation of the chord keystrokes and produce "on-line" visual feedback of the data being entered.

7.4.4 Levers, Dials, and Special Pushbuttons and Switches

Comparison with Keyboards

The major conclusion to be reached with respect to levers, dials, pushbuttons, and switches for data entry is that keyboards are better. This is true even for unskilled operators making occasional entries. The major comparison study is by Minor and Revesman (1962) in which a ten-key keyboard, a matrix keyboard, levers, and rotary knobs were compared. The ten-key keyboard was best in terms of accuracy and preference, and it was faster than all others except for the full matrix keyboard which was approximately equal in speed of entry.

If the frequency of data entry and/or the skill of the data entry operator calls for "touch" operation, the ten-key keyboard is to be pre-

ferred for the entry of numeric data, and the typewriterlike keyboard for the entry of alphabetic information. Only in those cases where design or economy considerations rule out a keyboard should consideration be given to other forms of pushbuttons, switches, dials, and levers for the entry of digital or numerical data.

Keyboard Overlays and Modular Keys

A great variety of switches, dials, etc. are available on the commercial market. (See Hillenbrand 1967.) A recently announced system incorporates a book of keyboard overlays with coded contacts actuated as the pages in the book are placed over the keys. With this overlay system, relatively few keys may control many different functions as the different page overlays are used. Other recent announcements involve modular keys to be arranged in patterns for panels and keyboards according to design requirements. By means of interrupted light beams, magnetically actuated reed switches, and/or magnetically actuated solid-state circuitry, each modular key can create its own coded output, as required by the overall system design.

Dials and Thumb wheel Switches

Several studies have explored data entry by means of devices other than keyboards. Conrad (1958) found the rotary telephone dial less accurate than a ten-key pushbutton keyset if the data message had to be held in memory until entered. This effect is attributable to the delay introduced by the return of the dial before the next digit can be entered. Deininger (1967) compared the rotary telephone dial with ten thumb wheel switches for entering phone numbers and found the dial to be faster, and preferred, for random sequences of phone numbers. Plath and Kolesnik (1967) examined the use of thumb wheel switches for entering navigational coordinates in an aircraft. Entries took approximately 2.75 sec. per wheel setting, with approximately a 2% error rate. The wearing of flight gloves made no significant difference.

Pushbutton Keyset

Deininger (1960a and b) explored the entry of phone numbers on a telephone pushbutton keyset. Little or no difference in performance was found as a function of the size, force-displacement, presence of snap action, and presence of auditory feedback. (See "Keystroke Touch and Stiffness," in Section 7.5.3 for further discussion.) There are no design-relevant data.

Applications of Levers, Dials, Pushbuttons and Switches

Use keyboards wherever possible in preference to levers, dials, pushbuttons, and switches for the entry of numeric and/or alphabetic data. For unskilled operators and/or occasional entry of information it is desirable to provide a visual indication of the characters entered so that the operator may sight check the data prior to its actual entry into the data processing system. In situations such as the telephone where the entire message is not stored in the terminal prior to "entry," visual feedback is apparently unnecessary. Recommendations concerning visual feedback are based on "educated guesses"; there are no data.

7.4.5 Consoles for Data Entry

General Considerations

Consoles for data entry are relatively new. Each is typically designed for a specific job or class of jobs. There are too many varieties and variations possible both in experimental and commercially available units to permit a meaningful classification and recommendation. Almost without exception, the results of any study comparing two or more console configurations must be interpreted within the limits set by the task for which the system was designed, and by the task used to evaluate human performance at the console. What is needed are several "standard" tasks which are designed to represent the spectrum of tasks for which consoles are expected to be used. To the extent that investigators incorporate these standard tasks into their experimental evaluations, would comparisons of performance data be meaningful for making evaluations amongst the console con-

figurations. The design of such "standard" tasks is *not* an easy job.

Several reports (Barmack and Sinaiko, 1966; Devoe, 1967; Devoe et al., 1966; and Technology Profile, 1968) describe many commercially available, and experimental, data entry consoles. Typical applications are also described in Technology Profile (1968). Dolotta and Selfridge (1968) provide a listing of features for a typewriterlike time-sharing terminal, with accent on the user's (programmer) point of view. Though they provide no performance data, their arguments and opinions are convincing. Suppes (1966) describes some of the features he considers desirable for consoles, in systems designed for computer-assisted instruction. While Dolotta and Selfridge concentrated on the features for a typewriterlike terminal, Suppes indicates that a console terminal limited to a typewriterlike mechanism would be just a minimal console for his purposes. He favors analog, graphic, and voice inputs to the system and outputs to the operator. Siders (1967) provides similar descriptive information for console features for active interaction between computer and designer in carrying out engineering design tasks.

Semling (1968) describes the data processing system at the Internal Revenue Service (IRS), where the system currently punches and transcribes to magnetic tape more than 600 million punched cards each year. He reports that there are about 500 keypunch machines at each of seven regional IRS centers. An experimental system is currently under evaluation which includes a cathode ray tube and keyboard console along with additional hardware to enter and verify the volume of data directly to magnetic tape. Though this appears to be an ideal situation for a careful performance evaluation of competitive systems of data entry, once again, no performance data are available.

Hand Printing vs. Keyboard Entry for Console Tasks

Performance data for a simulated console task are reported by Devoe (1967). A task involving the making of measurements on a drawing, table look up, computations, and data entry was studied with respect to the relative desirability of hand printing the data entries on printed forms versus making the entries via a typewriterlike keyboard. Keying was only slightly slower than hand printing for the non-typist subjects. Practice would presumably eliminate that difference in less than a week of full-time work. Errors were relatively few, not systematically distributed, and not reported. The need to keypunch the hand-printed material adds a further time delay for that mode of data entry, and in somes cases this is a critical delay before the system can interact with the console operator. It is important to note that in this study data entry was a small though crucial part of the total task performed. In this respect it is the only study of its kind in the literature.

Devoe and Graham (1968) further explored the possibility of utilizing hand-printed entry of data at a console. Operators made printed entries on paper placed over a tabletlike entry device. This gave information to the computer analysis system with respect to the sequence of printed strokes as well as to their form, making machine recognition of the capital alphabetic characters and numbers considerably simpler. The character recognition task was made still simpler by imposing certain constraints on the shapes and sequences of strokes for each of the characters which were acceptable. The authors conclude, "With relatively little practice, most subjects were able to learn all constraint sets and to copy difficult messages with reasonably good speed and accuracy." The data indicate printing rates just under 30 characters per min. with about a 3% error rate for the on-line hand printing. The incorporation of a correction cycle reduces the error rate close to zero, with an entry rate of about 20 characters per min. overall. The authors recommend on-line hand printing as a mode of data entry for tasks calling for occasional data entry on the part of the operator. An important feature of hand-printed data entry is the fact that the entry may be made with just one hand.

Barmack and Sinaiko (1966) mention a five-button keyboard developed by Englebart for one-hand entry of alphabetic information. They report data for one subject (Englebart) who eventually reached 35 w.p.m. with his right hand. Dvorak (1950) also describes a

one-hand keyboard, but reports no performance data.

Whether or not a typewriterlike keyboard is an appropriate data entry device for a console depends in part at least on the proportion of people in the user population who know how to type. A small informal survey by Barmack and Sinaiko (1966) indicates that about 75% of professional scientists and engineers have a "working familiarity with a standard typewriter."

It is recommended that in most cases a typewriterlike keyboard be utilized if the volume of data entry is at all heavy. Further, the keyboard should conform to the recommended typewriter standard shown in Figure 7-3a. However, in those situations where entries are relatively infrequent, or are a small part of the total task being performed, or where it is important to keep one hand free, it is strongly suggested that consideration be given to on-line hand-printed data entry. This set of conditions however, also suggests voice entry as an ideal mode of data entry. When practical systems are developed for voice entry, this mode should also be evaluated. (See Section 7.4.7, "Handwritten Inputs," for further information.)

7.4.6 Graphic and Analog Inputs

There are many hardware and programming systems for achieving graphic and analog inputs to data processing systems (e.g., Barmack and Sinaiko, 1966; English et al., 1967; Licklider, 1960; Ridinger, 1967; Siders, 1967; Suppes, 1966; Sutherland, 1966a, 1966b). The March 1967 issue of *IEEE Transactions on Human Factors in Electronics* (HFE 8) is devoted to man-computer, input-output techniques, and many of the articles contain descriptions of on-going work and developments.

Some of the devices utilized for entering analog information are described by English, et al., (1967) and include a joystick, the Grafacon, a "mouse," a knee control, and a light pen. The "mouse" is a small box which is moved by the operator on a tablelike surface in order to transmit the X-Y coordinates for the cursor. The knee control uses a left-right and an up-down movement for the X and Y coordinates. These devices were compared in a task calling for the manipulation of a cursor in a text manipulation system. The results, however, are specific to the particular configurations used.

While devices for graphic and analog entry are many, comparative data are few. Compatibility and spatial correspondence between display and control movements are the only general principles which appear to be supported with data (e.g., Earl and Goff, 1965; Leonard, 1964).

7.4.7 Handwritten Inputs

Comparison Among Modes

Several studies have examined characteristics of handwritten and printed characters for data entry. For example, Devoe (1967) reports free cursive handwriting at a rate of approximately 80 characters per min., typing by non-typists at about 50 characters per min., unconstrained printing at about 60 characters per min., and constrained printing at about 35 characters per min. All rates but cursive handwriting were still showing improvement at the end of the experiment. Errors were at the 1% level or less at the end of the experiment except for the constrained printing where it was about 3% (almost entirely due to lack of conformity with constraints). (See Section 7.4.5, "Handprinting vs. Keyboard Entry for Console Tasks" for additional information and comparisons.)

In another experiment (Devoe, 1967), subjects printed random numbers at about 100 per min. and random letters at about 75 per min., where each character was printed in a ½-in. block on a specially provided form. These entry rates may be compared with those reported by Hirsch et al. (1960) for constrained numeric printing. The digits were printed at about 20 per min., with an error rate of 0.32% for automatic recognition, but an error rate of only 0.11% attributable to incorrect or transposed digits. The comparison between the two reports shows very large differences in rate of printing and in rate of error production. The Hirsch et al. experimental conditions obviously placed greater emphasis on careful and correct printing. Conrad and Hull (1967) report the copying of digits at approximately 90 to 100 digits per min. with no constraints on the printing, and between 0.1% and 0.3% of characters in error. Thus, error rates

are comparable in the Conrad and Hull study and in the Hirsch et al. study. The constraints for the Hirsch et al. study very markedly reduce the rate of printing. More powerful character recognition systems, permitting less constraint in printing, should permit higher rates of hand printed data entry.

Errors in Handwriting

While overall production and error rates are of interest for system design, more detail is needed with respect to the errors that are made in order to guide the design of character recognition systems, and error detecting and correcting codes. The first feature of the error data worth noting is that a few operators produce a large proportion of the total number of errors observed. Hirsch et al. (1960), for example, report that three out of their 100 subjects accounted for 22% of the errors made, and these subjects tended to be consistent in the kind of error they did make. McArthur (1965) and Crook and Kellogg (1963) report similar results. Identifying error-prone operators can reduce overall error rates.

The frequency with which a given class of error is found is heavily dependent upon the details of the copying task. Conrad and Hull (1967) report, e.g., where short-term memory is not involved, transposition errors account for about 5% of the total errors, while they account for more than 20% of the errors if short-term memory is involved. If the copying task is such that the operator may easily lose his place in the original message, then as many of 50% of the errors will be the omission of one of the digits, while in cases more typical, this percentage is usually between 5 and 10%. The most frequent error, by far, is the substitution of one character for another. This may run as high as 80% of the total digit errors when strings of digits are copied directly below those presented.

When capital alphabetic characters are included in the material to be hand printed, substitution errors are by far the most frequent, accounting for more than 80% of the errors in the Conrad and Hull study. Illegible and omitted characters are next in frequency. Chapdelaine (1963) and McArthur (1965) report data for similar tasks.

Substitution errors may be further analyzed in terms of which characters are substituted. McArthur (1965) reports 0 (zero), 8, B, D, I, O (Oh), and Z as the characters which most frequently had other characters substituted for them. These 7 characters accounted for 72% of the substitution errors, with 8, I, and O (Oh) as the most frequent three. Characters which were substituted for these eight characters were almost always "iconic" (i.e., "look-alike"): e.g., O (Oh), 6, D, and U for 0 (zero); B for 8; etc. These data are important but are difficult to place in context because there are no reports of the rates at which the letters and numbers were transcribed, i.e., only error data are reported.

Off-Line Handprinted Input

At least two different automatic off-line hand-printed character recognition devices have been described in the literature (Greanias et al., 1963; Simek and Tunis, 1967). Recognition rates greater than 99% of the digits written are reported. Commercial units for reading hand printed digits (and several alphabetic characters as well) were announced as early as 1966.

7.4.8 Mark-Sensed Answer Sheets

The only performance data comparing mark-sensed answer sheet marking with other forms of data entry are reported by Devoe (1967). While hand printing led to entry rates of 100 digits per min. or 75 alphabetic characters per min., equivalent entries on mark-sensed answer sheets were 65 per min. and 15 per min.

Mark-sensed answer sheets should not be used as a routine form of data entry for either numeric or alphabetic information. However, in situations where each of a great many operators are to enter a relatively small amount of data, the mark-sensed answer sheet may be a desirable mode for data entry. When the automatic recognition of hand-printed characters becomes more economical and readily available, it is anticipated that the need for the mark-sensed form of data entry will be completely eliminated.

7.4.9 Preperforated Punched Cards and Mark-Sensed Cards

The only performance data available are in a

study by Kolesnik and Teel (1965) in which navigational data were entered onto cards by means of three simple manual methods. The results suggest that preperforated punched cards or mark-sense cards are preferable to thumb wheels, push buttons, or hand-punched cards. Improved availability and cost of automatic recognition devices for hand printed characters should lead to a preference for that mode of entry in most situations which utilize the prepunched card or mark-sensed card.

7.4.10 Acoustic Input

Experimental acoustic recognition systems for the ten digits (and several additional words) have been demonstrated with at least 98% recognition capability (Licklider, 1960; King and Tunis, 1966.) Commercial systems are not yet available. Assuming that acoustic recognition systems are feasible and practical, under what conditions would they be desirable as means for data input?

Braunstein and Anderson (1959) studied the relative speed and accuracy of reading digits aloud and keypunching digits for five experimental subjects with no prior training. Subjects read digits at about twice the speed at which they could keypunch, even after several hours of practice; but the keypunching was an easier task. When given the option, four of the five subjects chose to punch rather than read the 1,050 digits which had to be entered. Subjects averaged a reading rate between 2.5 and 3 digits per sec., and a keypunching rate between 1 and 1.5 digits per sec. Reading errors were not very different in number from keypunching errors. The reading was a more tiring task for all of the subjects, but it is uncertain whether additional training (e.g., in breath control) would change this. A trained keypuncher performing the same task entered digits at 2.8 per sec., and this was probably slightly below her usual rate due to a difference in machines. The authors concluded that voice input does not offer speed or accuracy advantages over conventional keypunching by experienced operators. Thus, vocal entry of digital data appears to be highly desirable only where the amount of data to be entered is relatively small and the frequency of entry is low. If the volume of data entry is large, some form of keyboard entry is preferable. Performance data for data entry of larger vocabularies are not available. The reading of words might be both a preferred and more accurate mode for alphabetic data entry, but there are no performance data nor are there devices readily available for accurately recognizing a large acoustic vocabulary.

7.4.11 Character Readers

Character recognition machines are ideally suited for reading straight typed copy, where each page of copy is a loose unit, i.e., a page or card. The recognition system becomes less complex and less expensive if all the data appear in a *single stylized* type font. A special type font has been suggested as a standard (Standards, 1968b). Newer and more powerful units, however, are able to read as many as 200 different type fonts, for example, and a standard *stylized* font appears superfluous. Character readers still have problems, however, in dealing with bound volumes, illustrations, citations, and footnotes. Thus, completely automatic read-in of periodicals and books is not yet feasible with commercially available units.

The character reader coupled with a team of typewriter operators is competitive with other high-volume data entry systems. Helweg (1962) estimated a break-even point at approximately 10,000 pages per day in comparing key-punching with character reading at that time. Even at that point, he indicates, the character recognition equipment would provide higher speed and greater accuracy.

Fein (1967) reports that the optical reader used at the Social Security Administration has replaced 150 keypunch operators, and is reported to have an error rate of better than 1 error in 1,728 characters.

If the volume of raw data to be entered into the computer system is very large, and is available in typed or printed form on separate sheets of paper or card, an optical character recognition system may appear warranted to achieve higher entry rates and greater accuracy. Character recognition devices for hand-printed, alphanumeric characters are currently in experimental development. For digital data they are already available commercially. Thus, even hand-printed data

may be read directly into computer systems. However, the current character recognition systems are quite expensive, and alternative means of data entry may be preferable for those situations involving relatively small volumes of data. (See Section 7.6.4 for additional comments.)

7.5 Data Entry Rates

7.5.1 Production

High-Volume Entry

For high-volume data entry of redundant data such as English text, a summary by Devoe (1967) reports that a typewriterlike keyboard provides the highest *character* entry rate, with speed test rates of 60 words (300 characters) per min. quite common, 100 w.p.m. more or less the upper limit likely to be found in production situations, and championship speed approaching 150 w.p.m. (See Figure 7-4.) These figures should be divided by approximately two to estimate daily production (as contrasted with speed-test performance). Experimental "abbreviation" typewriterlike systems (e.g., Klemmer, 1958; Lockhead and Klemmer, 1959; Seibel, 1962a) promise somewhat higher *information* entry rates, but commercial units are not available. The steno-type system provides the highest known *information* entry rate for English text, but it produces a phonetically encoded output which must then be translated to correctly spelled English (requiring sophisticated hardware and programming). The entry of straight numeric data is somewhat slower than that for highly redundant English text, primarily because numbers have close to a random distribution.

Keypunching

Considering many different data entry jobs (and several different keypunch installations), a rate of 170 characters per min. (2.8 per sec.) is a good estimate (Klemmer and Lockhead, 1960, 1962a, 1962b) of the mean rate of *daily* entry for time "spent at the machine," with an estimated range from 127 to 206 characters per min. including the middle 95% of the keypunch operators. Better operators will produce a daily average of more than 250 characters per min. for some (easier) data entry jobs. Klemmer and Lockhead (1960) report that there are no consistent differences between alphanumeric and straight numeric keypunching; hence, these production figures may be considered to apply to either. Straight English text "should" yield somewhat higher rates, but there are no data.

Typing

Droege and Hill (1961) report that typists, doing straight-copy 10-min. tests, average about 326 characters per min. (about 5.4 per sec., or 65.3 w.p.m.), with a range of 215 to 435 characters per min. (43 to 87 w.p.m.) including the middle 95% of the typists (and 36 to 94 w.p.m. for the middle 99%). Adjusting for *daily* production by dividing by "approximately two" indicates typing and keypunching have very similar daily production rates. However, daily production typing figures are not available, and it is not possible to determine whether "two" is the correct number by which to divide for estimating daily typing production. "Approximately two" (1.8) does work for keypunching and 20-min. to 30-min. speed tests.

Production Rate and Error Correction

The ease with which self-detected errors may be corrected, can have a marked influence on overall production rate. The common keypunch is notoriously awkward in this respect, as is the typewriter. The newer keyboard to-tape systems (and other similar systems) are decidedly better in this respect, and in terms of correcting errors found by the verification process. Comparative data are not available.

Unskilled Operator Production

The entry of data by relatively unskilled operators making occasional entries varies from approximately 100 digits per min. for unconstrained hand-printed numbers down to approximately 20 alphanumeric characters per min. for constrained hand printing with an error-correction cycle to reduce errors close to zero. Typewriter and 10-key numeric keyboards (used by unskilled operators) provide entry rates which are approximately equivalent to hand printing, and perhaps slightly better if one takes into account the

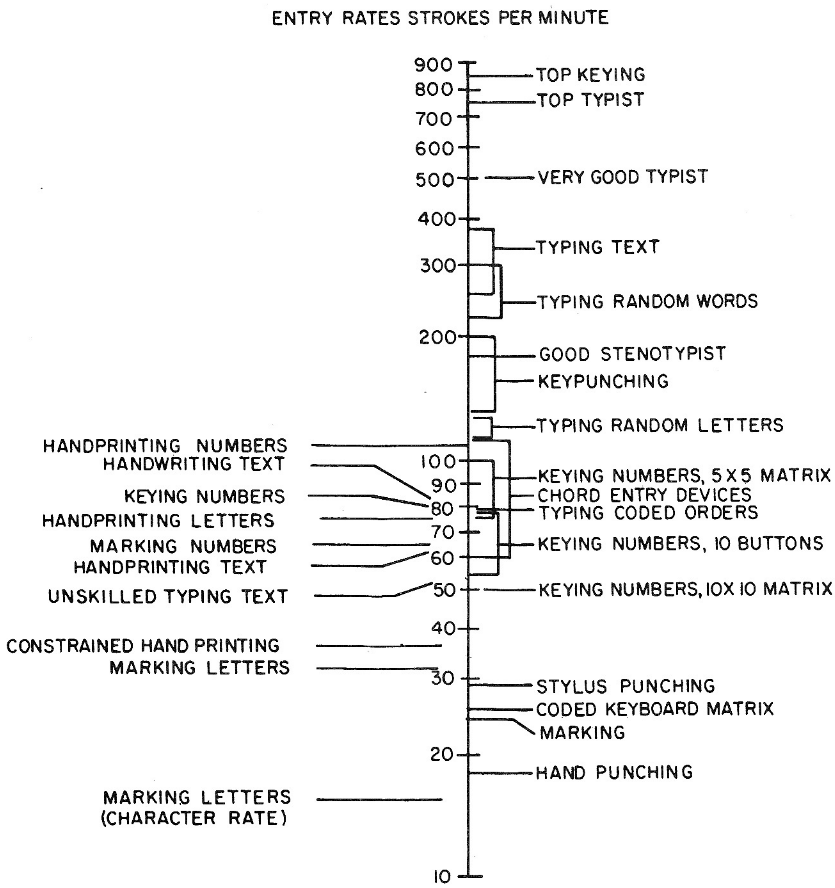


FIGURE 7-4. Representative manual entry rates (adapted from Devoe, 1967).

necessary constraints to handwritten material in order for it to be machine readable. The hand printing however, requires only a pencil (or its equivalent) and the use of just one hand.

Figure 7-4 shows representative manual entry rates for various types of devices in terms of characters entered per minute.

7.5.2 Errors

Keypunching

Production data (Klemmer and Lockhead, 1960, 1962a, 1962b) indicate average error rates for different keypunch installations ranging between 1600 and 4300 keystrokes per undetected error (0.2% and 0.06% keystrokes in error). Self-detected, and self-corrected, errors ("restarts") are four or more times as frequent. Whether most operators make many errors and a few are very accurate, or most operators are quite accurate and a few make many errors, depends on the error measure used. Adjusting for differences in measures, the logarithm of percent keystrokes in error suggests an approximately symmetrical distribution about the average error rate for a given installation, with a few very accurate operators.

Distributions of operator error rates for different installations, and groups of operators at grossly different skill levels, are essentially equivalent except for differences in median error rates. The distributions indicate that the operators at the high end of the distribution (90th percentile) make six to ten times as many errors as the operators at the other end of the distribution (10th percentile). The higher an operator's average error rate, the more variable will be her error rate from week-to-week (essentially a linear relationship). The fastest operators tend to be the

most accurate, though the relationship is not very strong (correlation of 0.4 to 0.5). Operators continue to show improvement in error rates for at least a year or two on the job.

Approximately 70% of keypunching errors (Klemmer and Lockhead, 1962b) involve a single character. Two or more characters were transposed for about 15% of the errors, a character was omitted for 4% of the errors, an extra character was inserted for 1% of the errors, and procedural errors accounted for the remaining 10% of the errors. Approximately 80% of the single-character numeric errors were "aiming errors" in that adjacent keys (horizontally or vertically) were struck instead of the intended one. Westhoff (1962, as described in Conrad, 1967) reports a similar high frequency for aiming errors.

Typewriting

Typewriting data analyses (e.g., Flynn, 1959) suggest similar aiming errors as most frequent, some "opposite hand" errors, omit errors, and some other particular substitutions of one letter for another. These studies also indicate that the frequency with which a letter or word is involved in an error is very closely related to the frequency of use of that letter or word in the English language.

Effects of Memory Load

If data are held in short-term memory, and entered from memory, then the aiming errors tend to disappear and memory errors become more frequent. Memory errors involve "chunk" confusions, "acoustic" confusions, and forgetting of central and latter parts of messages.

Verification, Proofreading, and Error Correction Procedures

Verification and error correction procedures are much more convenient if the correction procedure does not involve duplicating a portion of the data and the removal of a faulty data card. A simple back up and write over is the preferred mode of error correction.

Some data entry systems call for proofreading rather than verifying. In proofreading, certain omitted letters are more likely to be overlooked than others; missing letters which *are not* pronounced are much more likely not to be detected than are missing letters which *are* pronounced; the probability of failing to detect a missing silent letter is greater when the letter occupies positions early in a word than it is when a letter occupies positions toward or at the end of the word. The final pronounced "e" in the word "the" is a special case with a high probability of of failure to detect the missing letter. (See Corcoran, 1967, and Corcoran and Weening, 1968.)

There are no data giving comparative error detection rates for verification versus proofreading procedures.

Damerau (1962) reports on a computer program to detect and correct common data entry spelling errors in English text. For one test sample, better than 90% of the misspelled words were identified. Thus, a computer could be used to compensate for a very large percentage of data entry errors. Whether or not to use it is a question of cost. Commercial packages are not available on the market.

The commonly used "*net* words per min." score for combining speed and error rates is based on very untenable assumptions (Hirsch, 1958), and should not be used. Better combination scores have been developed, but gross speed and error data should *always* be reported in addition to any combination score that may be used.

Keystroke Timing and Key Interlocks

Inter-keystroke intervals of 50 msec., and less, will be found for skilled operators in high-volume data entry tasks (Fox and Stansfield, 1964). The present author *estimates* that enforced inter-keystroke intervals of 10 msec. or less will cause essentially no detrimental effects, while enforced inter-keystroke intervals of 100 msec. or greater will most certainly cause detrimental effects. There are no data adequate to the task of providing the design engineer with the necessary trade-off functions for enforced inter-keystroke intervals between 10 and 100 msec. "Armchair estimates" do not appear to be advisable. (See Section 7.3.4., "Delay reduces speed of typewriting.")

Effects of Training and Time on the Job

Performance on data entry tasks shows improvement with practice over periods at least two years long (Klemmer and Lockhead, 1960, 1962a, 1962b), and estimates of high-volume data entry production should not be based on operator performance unless at least 6 months of practice on the particular task has been taken into account. There are no *reliable* "short-cuts" or "cheap ways out" (Seibel, 1964b).

The actual mode of operation and abilities involved in performing data entry tasks, shifts with practice and improvement in performance (Fleishman, 1960 and 1965; Leonard and Newman, 1964). At higher levels of skill, data entry operators are utilizing the redundancies in the input data to encode that data into "higher order units" which are then processed as units. This is to be contrasted with the character-by-character mode of entry which is typical of the operator at a low level of skill, early in practice. Thus, the same prediction and screening tests which worked for low levels of performance (early in practice) will probably not work for higher levels of performance (later in practice), and the effects of variables which influence data entry performance at low levels of skill will most likely not act in the same way in influencing performance at higher levels of skill (e.g., response speed as a function of information per response). *Reliable* and *valid* data for highly skilled high-volume data entry performance are expensive to obtain.

7.5.3 Effects of Special Modifications in Entry Devices

Keystroke Storage

Though single keystroke storage is now available in many commercial keyboards, there are no published data known to the present author which compare the single stroke storage units with other units in terms of data entry performance.

Erase and Delete Actions

Erase and delete features for data entry tasks are reported to be highly desirable (e.g., Semling, 1968), but no experimental data are available in the open literature. Since operators at higher levels of skill tend to work with higher order units of the data, e.g., words rather than single characters, it is reasonable to expect a "word erase feature" would be highly desirable. At lower levels of skill, or for the entry of data with very little redundancy (e.g., the usual numerical data) a single character erase feature *may* be more desirable. Data are not available in the open literature.

Visual and Auditory Feedback

Visual and auditory feedback appear to be unnecessary for the highly skilled high-volume data entry operator performing under speed-test conditions (e.g., Diehl and Seibel, 1962). However, other studies have shown that the removal of visual feedback does have a detrimental effect on the number of errors which the data entry operator makes, or fails to detect (e.g., Devoe et al., 1966; Devoe, 1967; and West, 1967). These and two studies by Chase, Harvey et al. (1961) and Chase, Rapin et al., (1961), lend support to the conclusion that the major source of feedback for the highly skilled operator is the kinesthetic-proprioceptive-tactual feedback which the operator gets from actually making the movement and striking the key. The West data suggest that reliance on these proprioceptive cues increases with skill level, but even at high levels of skill the operators utilize visual feedback for further reductions in errors. Thus, the removal of auditory feedback may be expected to have relatively little effect on performance, but the removal of visual feedback can be expected to lead to higher error rates.

Keystroke Touch and Stiffness

There are no data in the open literature with respect to keystroke touch, stiffness, and "feel" on high-volume data entry tasks.

Descriptions of the force-displacement characteristics of some commercially available switches and push buttons are found in Pollock and Gildner (1963), but the effects of variations in force-displacement characteristics on data entry performance are not available.

Two studies by Deininger (1960a and 1960b) describe force-displacement characteristics for keys to be used in the entering of telephone

numbers, and occasional-entry performance data indicate no difference as a function of the force-displacement variations.

In general, most keyboards exhibit an increasing amount of force required as the key is depressed, with a marked drop-off in necessary force as the entry (typing) mechanism is tripped, and then a relatively sharp further increase in force requirement as the key is "bottomed." Most electrically operated keyboards call for a relatively light touch in order to trip the entry mechanism, frequently in the range of 2 to 3 oz. There are no performance data to indicate the effects of increasing, or decreasing, this force requirement; nor are there data to indicate the effects of changing the characteristics of the force-displacement function, or its variations under dynamic conditions.

7.6 Factors in Selecting Data Entry Systems

7.6.1 Training and Type of Keyboard

The highest levels of high-volume data entry performance are achieved only by extensively trained and highly skilled data entry operators. If this training is done by the data entry employer, it often involves very extensive investments in time before high rates of production are achieved. To the extent that typing skill can be employed in the data entry task, the data entry employer saves a great deal of time and money, as most applicants have already been taught to type.

Thus, data entry devices should be as much like typewriters as possible. Even for the occasional entry of data, the majority of high school graduates in the United States has some familiarity with the standard typewriter keyboard, and thus would be better able to use it than to use some other arrangement.

If special non-typing populations of operators are to be considered (e.g., postal mail-sorting clerks), then other forms of keyboard arrangements may be defensible (e.g., Conrad, 1960b and 1960c).

Entry rates higher than those which may be achieved with a standard typewriterlike device can be achieved with some chord keystroke devices. Typically, such chord keystroke devices require more extensive training periods in order to achieve this higher data entry rate. Thus, if personnel turnover is expected to be high, the investment in additional training may not be warranted. A compromise system, which is a variation of a standard typewriter keyboard, and which permits useful data entry production while the chord strokes are being learned, appears to be a reasonable way to overcome this "bind" (Seibel, 1962a and 1964a).

7.6.2 Instructions and Incentives

Instructions and incentives appear to have a relatively potent effect on the production of data entry operators. Pay, or bonuses above basic pay, which are related to level of production, should lead to higher overall production. For a variety of reasons this does not always work out that way. A major shift from this "operator-is-a-machine-component" attitude has recently been reported (The Christian Science Monitor, 1968). The report indicates that the output of key punch operators can be radically improved by "enriching" the job. Until recently "the key punch girl punched information onto a data card. Then usually her work was 100% verified. . ." In an experimental installation, operators are "given responsibility for a certain task (say, the payroll of one department) and are recognized as experts in this job. Any mistakes are fed back directly to the girl instead of to a supervisor. The key punch operator may decide, only if she likes, to have her work sample verified. She schedules her down day" (The Christian Science Monitor, 1968). With this arrangement, output was up, there was no loss in accuracy, and absenteeism and turnover dropped. The results may be reflecting only the classic "Hawthorne effect" but, if the phenomena are "real", the potential pay-off is very great. More careful evaluation is needed.

7.6.3 Machine Pacing

On occasion, incentive or machine-design considerations have led to the utilization of a machine-paced data entry station (e.g., mail-sorting machines). Machine pacing should never be used as an incentive device. And, permitting self-pacing by the operator, without artificial delays or speed-up attempts, is worth a con-

siderable amount of additional engineering effort and cost, as it will lead to sizeable increments in throughput. (See Section 7.3.4, "Machine pacing reduces speed of letter sorting.)

7.6.4 Keypunch, Paper Tape, Magnetic Tape Typewriter, and Character Recognition

Four major equipment systems are competing in the current market for high-volume data entry. The popular key punch, and somewhat less popular punched paper tape, appear to be losing ground to newer systems in which data are transferred from keyboard to some form of magnetic tape or disc storage.

A fourth system is the production of typewritten material followed by automatic character recognition equipment. One characteristic of the keyboard-to-magnetic-storage systems which is an important advantage, is the feature which allows for rapid and easy correction of self-detected and of verification-detected errors. If the *original* data source is in the form of typewritten material, with relatively clean and error-free copy, then character recognition appears to be highly promising. If the original data are handwritten, scattered here and there, and/or otherwise irregular and calling for organization and interpretation by the data entry operator, then the keyboard-to-magnetic-storage techniques appear to represent the best of the systems currently available.

The present author suggests that it may be highly advantageous to use small special purpose computers for on-line data entry so that abbreviations, standard formating, phrase writing, and certain levels of editing, and error correction, can be accomplished at the point of data entry.

7.6.5 Special Abbreviation Codes

The utilization of special "abbreviation" codes, with either standard or special chord keyboards, involves an additional set of trade offs and compromises. Several of the coding schemes which have been developed for the sorting of the U. S. mail are described by Cornog and Craig (1965) and Cornog et al. (1963). Seibel (1962a and 1964a) discusses the variables and trade offs involved. They include frequency of usage of each "abbreviation," number of keyboard strokes involved and/or the motor difficulty of the chord entry, and the size of the abbreviation vocabulary. Decisions with respect to these variables are certainly expected to affect throughput and training time, but the trade off functions are largely unknown. One reasonably well established principle, however, is that the more information transmitted with each keyboard entry, the faster will information be entered.

7.6.6 Occasional Data Entry

For situations involving occasional data entry, there are two major competing systems to be considered. The first is the utilization of the standard keyboard arrangements which are used in the high-volume data entry situation. The second is the utilization of handwritten characters and on-line character recognition devices, or off-line character recognition devices. In situations where the keyboard is a major distraction and inconvenience (e.g., man–computer interacting systems for problem solving, design, editing, etc.), the use of handwritten characters for data entry appears highly desirable. The current expense of the character recognition devices and systems limits their current usefulness. Where the keyboardlike device is not a major distractor, it is preferred, as it is currently available, relatively cheap, and can produce highly accurate and relatively rapid data entry. A third approach for the occasional entry of data is via voice. Experimental systems have been built for recognizing the spoken digits and some additional vocabulary, but commercial systems are not yet available. This method of data entry should prove least distracting of all, and leaves both hands free. It is currently limited to small vocabularies and experimental devices, and is definitely not preferred by the operator if there is any appreciable volume of data to be entered, but it should prove highly desirable for man-computer interacting systems if and when it becomes commercially available.

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